PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : G01B 11/26, H03M 1/22, G09G 3/00 | A1

(11) International Publication Number: WO 95/02163

(43) International Publication Date: 19 January 1995 (19.01.95)

(21) International Application Number: PCT/US94/07531

(22) International Filing Date: 1 July 1994 (01.07.94)

(30) Priority Data:
08/088,802 8 July 1993 (08.07.93) US
08/186,697 25 January 1994 (25.01.94) US

(71) Applicant: SCIENCE ACCESSORIES CORP. [US/US]; 2 Research Drive, Shelton, CT 06484 (US).

(72) Inventors: SINDEBAND, Seymour, J.; Stone Hill Road, Pound Ridge, NY 10576 (US). STONE, Thomas, L.; 4 Wolf Avenue, Beacon Falls, CT 06403 (US).

(74) Agent: NOVACK, Martin; 1465 Post Road East, Westport, CT 06880 (US).

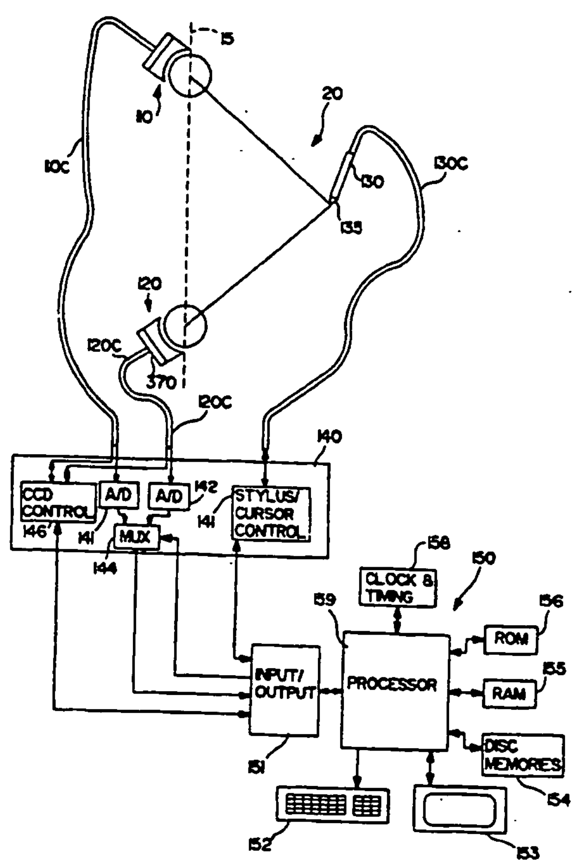
(81) Designated States: CA, CN, JP, KR, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: POSITION AND ANGLE DETERMINATION USING LIGHT

(57) Abstract

An apparatus is disclosed for determining the position of a moveable element (130). First and second spaced apart optical receiving assemblies (110, 120) are provided for receiving light from the moveable element. Each of the optical receiving assemblies includes an array of photosensitive elements (270, 370), a cylindrical lens (260) for receiving light from the moveable element, and a fiber optical block (250), formed of a multiplicity of optical fibers, optically coupled between the cylindrical lens and the array of photosensitive elements. An optical diffuser (259) is provided on the input surface of the fiber optical block, the diffuser operation to scatter some of the arriving light, and causing more light to be captured by the optical fibers, particularly near the ends of the fiber optical block. Also, the efficiency of a light-emitting cursor is increased by directing light that would otherwise be lost in the vertical direction, into a generally flat beam. This is achieved with a toroidal lens (1280) having a convex periphery.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria
AU	Australia
BB	Barbados
BE	Belgium
BF	Burkina Faso
BG	Bulgaria
BJ	Benin
BR	Brazil
BY	Belarus
CA	Canada
CF	Central African Republic
CG	Congo
CH	Switzerland
CI	Côte d'Ivoire
CM	Cameroon
CN	China
CS	Czechoslovakia
CZ	Czech Republic
DE	Germany
DK	Denmark
ES	Spain
FI	Finland
FR	France
GA	Gabon
GB	United Kingdom
GE	Georgia
GN	Guinea
GR	Greece
HU	Hungary
IE	Ireland
IT	Italy
JP	Japan
KE	Kenya
KG	Kyrgystan
KP	Democratic People's Republic of Korea
KR	Republic of Korea
KZ	Kazakhstan
LI	Liechtenstein
LK	Sri Lanka
LU	Luxembourg
LV	Latvia
MC	Monaco
MD	Republic of Moldova
MG	Madagascar
ML	Mali
MN	Mongolia
MR	Mauritania
MW	Malawi
NE	Niger
NL	Netherlands
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
RO	Romania
RU	Russian Federation
SD	Sudan
SE	Sweden
SI	Slovenia
SK	Slovakia
SN	Senegal
TD	Chad
TG	Togo
TJ	Tajikistan
TT	Trinidad and Tobago
UA	Ukraine
US	United States of America
UZ	Uzbekistan
VN	Viet Nam

POSITION AND ANGLE DETERMINATION USING LIGHT

FIELD OF THE INVENTION

This invention relates to the determination of the position of elements in space and, more particularly, to an apparatus that utilizes light for determination of angles and for position determination.

BACKGROUND OF THE INVENTION

There have been several prior approaches to determination of the position of one or more moveable elements in two-dimensional or three-dimensional space. So-called coordinate digitizer tablets, which work on sonic, electromagnetic, resistive, and other principles, have become commonplace for uses such as inputting graphical information into a computer.

Position determination that utilizes light (defined herein as the spectrum including infrared, visible, and ultraviolet radiation) has certain inherent advantages. In addition to high immunity from environmental noise and temperature variation, light can be readily generated, transmitted and detected using available solid state semiconductor devices. Nonetheless, optical position determination has not achieved widespread commercial success.

There have been a number of prior art approaches for utilizing light to determine the position of one or more elements in space. In general, optical techniques for position determination in prior art approaches suffer one or more of the following disadvantages: relatively high complexity, high cost, limited reliability (e.g. from moving scanner parts), inconvenient operation, limited accuracy, and/or limited repeatability of measurements.

It is among the objects of the present invention to provide an optical apparatus for determining the coordinate position of moveable elements which overcomes disadvantages or limitations of prior art approaches.

SUMMARY OF THE INVENTION

A form of the present invention is directed to an apparatus for determining the position of a moveable element. In an embodiment thereof, means are provided for causing light to emanate from the moveable element. [The light source can be on the moveable element or can be remote from the moveable element, and reflected therefrom.] First and second spaced apart optical receiving assemblies are provided for receiving light from the moveable element. Each of the optical receiving assemblies includes an array of photosensitive elements, and optical means for directing received light to a region on the array that is related to the angle at which the light is received. Electronic processing means, responsive to the outputs of the arrays, are provided for determining the angles at which the light is received. Means are then provided for determining the position of the moveable element from the determined angles.

In an embodiment of the invention, the optical means comprises a cylindrical lens for receiving light from the moveable element, and a fiber optical block, formed of a multiplicity of optical fibers, optically coupled between the cylindrical lens and the array of photosensitive elements. In this embodiment, the array of photosensitive elements is a flat linear array, and the fiber optical block has a curved input face and a flat output face, with the optical fibers arranged to carry light from the input face to the output face.

In general, a disadvantage of employing a cylindrical lens to collect light and direct it toward an optoelectronic sensor, such as a charge coupled device (CCD) sensor, is that since the sensor is flat, the position of the light spot on the sensor varies in a non-linear relationship to the arrival angle of the light. A feature of a disclosed embodiment addresses and solves this problem; i.e., the optical fibers of the block have a cylindrical input surface and a flat output surface that conforms to the detector. However, a problem can arise with signal detection when the light from the moveable element is received at the optical assembly at a relatively large angle with respect to the center line of the optical receiving assembly; that is, in the situation when most of the light is incident near an end of the curved input surface of the fiber optical block. In this situation, the light should be carried, by the fiber optical strands, to a spot near an end of the detector array. However, in some cases, the amount of light actually reaching the extremes of the detector array in this situation can be less than is needed for accurate light spot detection. The reason is believed to be the angle at which the light is incident on the input surface of the optical fibers near the ends of the fiber optical block input surface, where the fiber ends are cut at a substantial angle with respect to their longitudinal axes. If a substantial portion of the light is arriving at too great an angle with respect to the axes of the fibers, the light may not be captured by these fibers for transmission to the detector array. In accordance with a feature of the present invention, an optical diffuser is provided on the input surface of the fiber optical block, the diffuser operating to scatter some of the arriving light, and causing more light to be captured by the optical fibers, particularly near the ends of the fiber optical block.

In accordance with a further feature of the present invention, the efficiency of a light-emitting cursor is substantially increased by directing light that would otherwise be lost in the vertical direction, into a generally flat beam. In an illustrated embodiment hereof, this is achieved with a toroidal lens having a convex periphery.

Further features and advantages of the invention will become more readily apparent from the following detailed description when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagram, partially in block form, of an apparatus in accordance with an embodiment of the invention.

Fig. 2 is a cross-sectional representation of an optical receiving assembly of the Fig. 1 embodiment.

Fig. 3 is a perspective view of the fiber optical block of the optical receiving assembly of the Fig. 1 embodiment, showing a small representative region of the fibers therein, and showing, broken away, a light diffusing coating in accordance with a feature of the invention.

Fig. 4 is an illustration of representative light rays focused by a cylindrical lens onto a curved surface.

Fig. 5A illustrates the type of intensity versus position pattern that is characteristic of a light spot focused on the photosensitive array by the cylindrical lens.

Fig. 5B shows the intensity versus position graph of Fig. 5A, with illustration of a type of processing in accordance with a disclosed embodiment.

Fig. 6 is a diagram useful in describing the relationship between receiving angle and rectangular coordinates for a disclosed embodiment.

Fig. 7 is a flow diagram of a routine for controlling the processor subsystem of Fig. 1 in accordance with a disclosed embodiment.

Fig. 8 is a flow diagram of the routine for collecting and storing data from the photosensitive detectors, as represented by the block 710 of the Fig. 7 routine.

Fig. 9 is a flow diagram of a routine for determining the center of the light spot for each detector, as represented by the block 720 of the Fig. 7 routine.

Fig. 10 is a flow diagram of a routine for determining arrival angle for each detector, as represented by the block 730 of the Fig. 7 routine.

Fig. 11 is a flow diagram of a routine for determining rectangular coordinates from the arrival angles, as represented by the block 740 of the Fig. 7 routine.

Fig. 12A shows a wireless cursor in accordance with an embodiment of the invention.

Fig. 12B illustrates a toroidally-shaped lens for directing light from the cursor into a useful vertical range, in accordance with an improvement of the invention.

Fig. 12C and 12D illustrate cross-sectional view of the embodiments of the toroidal-shaped lens of the Fig. 12B embodiment, illustrating conceptually the manner in which the light rays are collimated.

Fig. 13 is a schematic diagram that shows operation with a reflective cursor in accordance with another embodiment of the invention.

DETAILED DESCRIPTION

Referring to Fig. 1, there is shown an apparatus in accordance with an embodiment of the invention. A first optical receiving assembly 110 and a second optical receiving assembly 120 are mounted along a line 15 that generally defines a boundary of a region 20 in which the position of a moveable element 130 is to be determined. The line 15 is also the y axis of a reference rectangular coordinate system that will be described below. The moveable element 130 may be, for example, a cursor or a stylus (as shown), and has a light source 135 mounted therein. In the present embodiment, the light source is an infra-red source, such as one or more infra-red light-emitting diodes mounted at the end of the stylus.

Each of the optical receiving assemblies (110, 120) includes a photosensitive array, such as a CCD array (270, 370) and the arrays are respectively coupled with electronics 140 via cables 110C and 120C. The stylus 130 can be wireless (and use a battery power source, or be a reflector of light from a remote source), but is shown in the Fig. 1 embodiment as including a cable 130C coupled with the electronics 140, which may include a power supply in a stylus/cursor control block 141.

The electronics 140 is coupled with a processor subsystem 150, which may, for example, be a personal computer such as one based on an Intel 486 processor 159, and having associated functions and peripherals that are conventionally employed, including input/output interface 151, keyboard 152, monitor 153 disk memories, random access memories, and read-only memories 154, 155 and 156, respectively, and clock and timing circuit 158.

The electronics 140 includes analog-to-digital converters 141 and 142, which respectively receive signals from the CCD arrays of the optical receiving assemblies 110 and 120, and convert them to digital form. The outputs of the analog-to-digital converters 110 and 120 are coupled to a multiplexer 144 that is under control of the processor subsystem 150, and the output of the multiplexer 144 is coupled to the processor subsystem 150. The processor subsystem 150 is also coupled with the CCD control 146, that conventionally controls the read-out and resetting of the CCD arrays. This function, represented within electronics 140 in the Fig. 1 illustration, may alternatively be provided on the CCD chips.

Referring to Fig. 2, there is shown a cross-sectional view of an optical receiving assembly (110 or 120, 110 being shown) in accordance with an embodiment of the invention. A base 230, which may be formed of metal, holds a fiber optical block 250 that contains a multiplicity of optical fibers which, in the present embodiment, are in a configuration illustrated in Fig. 3. The fiber optical block has an input surface 252 in a curved concave shape (cylindrical, in this case), and an output surface 254 that is generally flat. The fiber optical block 250 may be formed by machining and/or cutting a conventional fiber optical block into the shape shown in Figure 3. A cylindrical lens 260, formed, for example, of glass, is mounted in the concave opening of the input surface of the fiber optical block 250, and slightly spaced therefrom. The lens 260 can be held in place by a substantially transparent epoxy material 255. If desired, the epoxy material may have a dark hue and can also serve as an infrared passing filter that helps to reduce any effect of spurious non-infrared radiation. [Alternatively, an air gap can be provided between the cylindrical lens and the fiber optical block, with the lens mounted at its ends in the base.] The output surface 254 of the fiber optical block 250 is coupled with the sensing elements of a photosensitive array

270 which, in the illustrated embodiment, is a linear CCD array, such a 2048 element linear array of the type sold by Sony Corporation. The array 270 is mounted in a slot in the base 230 and, in the illustrated embodiment, is contiguous the output face of the fiber optical block. The array 270 is coupled, via connector 275, to a circuit board 280 for coupling to the cable 110C.

Fig. 4 illustrates representative light rays focused onto a curved surface by a cylindrical lens. The characteristic pattern that results is evident from the thickness of the bars (which represent the number of rays and, therefore, relate to intensity) in Fig. 4 and is shown, as a function of position, in the exemplary graph of Fig. 5A. The typical pattern has two separated lobes, which are believed to result from the slight spherical aberration illustrated in Fig. 4. To achieve consistent detection of the position of the light spot on the detector surface, it would be advantageous to have the pattern move in a substantially linear fashion on the detector surface in relation to the arrival angle of the light. A curved detector surface, as illustrated in Fig. 4, helps to advance this objective, but commercially practical photosensitive detectors generally have a flat detector surface. A feature of the disclosed embodiment addresses and solves this problem. In particular, the optical fibers of the block 250 are formed in a cylindrical input surface and a flat output surface that conforms to the detector.

Consider the arrangement of Fig. 6, wherein the center line of optical receiving assembly 110 is at an angle ϕ with respect to the X direction, and the center line of optical receiving assembly 120 is at an angle θ with respect to the X direction. The distance between the assemblies 110 and 120 (i.e., the distances between the centers of their respective cylindrical lenses) is A. The light source is assumed to be at a point P, having coordinates P_x, P_y. The line through optical receiving assembly 110 and P is called line 1, and the line through optical receiving assembly 120 and P is called line 2. The equation of line 1 is

$$y=m_1x+b_1 \tag{1}$$

where m_1 is the slope and b_1 is the y-intercept for line 1. As seen in the diagram:

$$m_1=\frac{P_y}{P_x}=Tan(\alpha+\theta) \tag{2}$$

$$b_1=0 \tag{3}$$

The equation of line 2 is

$$y=m_2x+b_2 \tag{4}$$

where m_2 is the slope and b_2 is the y-intercept for line 2. As seen in the diagram:

$$m_2=\frac{-(A-P_y)}{x}=Tan(-\beta-\phi) \tag{5}$$

$$b_2=A \tag{6}$$

For any point (x, y), equation (1) can be rewritten as

$$y=Tan(\alpha+\theta)x \tag{7}$$

and equation (4) can be rewritten as

$$y=Tan(-\beta-\phi)x+A \tag{8}$$

Equating (7) and (8) gives

$$Tan(\alpha+\theta)x = Tan(-\beta-\phi)x + A \qquad (9)$$

and solving for x gives

$$x = \frac{A}{Tan(\alpha+\theta) - Tan(-\beta-\phi)} \qquad (10)$$

These relationships are utilized below when converting arrival angles to rectangular coordinates.

When using the technique as described hereinabove, a problem can arise with signal detection when the light from the moveable element is received at the optical assembly at a relatively large angle with respect to the center line of the optical receiving assembly; that is, in the situation when most of the light is incident near an end of the curved input surface of the fiber optical block 250 (Fig. 3). In this situation, the light should be carried, by the fiber optical strands, to a spot near an end of the detector array. However, Applicant has found that, in some cases, the amount of light actually reaching the extremes of the detector array in this situation can be less than is needed for accurate light spot detection. The reason is believed to be the angle at which the light is incident on the input surface of the optical fibers near the ends of the fiber optical block input surface, where the fiber ends are cut at a substantial angle with respect to their longitudinal axes. If a substantial portion of the light is arriving at too great an angle with respect to the axes of the fibers, the light may not be captured by these fibers for transmission to the detector array. In accordance with a feature of the present invention, an optical diffuser is provided on the input surface of the fiber optical block, the diffuser operating to scatter some of the arriving light, and causing more light to be captured by the optical fibers, particularly near the ends of the fiber optical block. Ideally, the diffuser should not unduly attenuate the light. In one preferred embodiment hereof, Applicant employs a so-called "opal" coating, which is a well known optical diffuser material which comprises a ceramic powder that can be applied to the fiber optical block input surface (such as by spraying a liquid suspension of the ceramic powder) and then heated and melted to achieve uniformity. This coating, which appears translucent, transmits most of the light (preferably, more than 80% of the infrared used in the present embodiment), but provides scattering that achieves the intended purpose. The coating is represented (broken away) in Fig. 3 by the reference numeral 259. It will be understood that alternatives can be employed. For example, a thin transmissive coating of a paint, such as a white pigment or other color pigment, can be used, but is presently considered less preferred. Also, it will be understood, that other means, such as a lens or lens system, could be provided for directing light near the ends of the fiber optical block at an angle that will facilitate capture by the fiber optical strands.

Referring to Fig. 7, there is shown a flow diagram which, when taken in conjunction with the further flow diagrams represented by the blocks therein, can be used to program the processor subsystem 150 (Fig. 1) to implement operation in accordance with an embodiment of the invention. The block 705 represents initializing of the system, which may typically be responsive to a power-up condition and/or an indication from the user that positional information is to be obtained. The block 710 is then entered, this block representing the routine, described in further detail in conjunction with Fig. 8, for collecting and storing optical signal representative data from the optical receiving assemblies 110 and 120. The block 720 is then entered, this block representing the routine, described in further detail in conjunction with Fig. 9, for determining the pixel location that is at about the center of the spot pattern that results from detection of the light source 135 (Fig. 1) on the CCD detector 270 (Fig. 2). The routine is performed for the data from each of the sensors 110 and 120. The block 730 is then entered, this block representing the determination, as a function of the previously determined center pixel positions, of the respective angles of arrival of the light from the moveable element 130. This routine is described in conjunction with the flow diagram of Fig. 10. The block 740 is then entered, this block representing the routine, described in further detail in conjunction with Fig. 11, for determining the coordinates of the position of the moveable element, using the previous determined angles. The block 710 can then be re-entered for the next cycle.

Referring to Fig. 8, there is shown a flow diagram of the routine, represented by the block 710 of Fig. 7, for collection and storage of data from the optical receiving assemblies 110 and 120. Inquiry is initially made (diamond 810) as to which mode of operation is active. In the present embodiment, coordinate position data can be continuously determined, or can be determined for individual points. In prior art coordinate digitizers, it is common for the moveable element (e.g. stylus or cursor) to be provided with a microswitch that the operator may, for example, activate by depressing the point of the stylus and/or by pressing a button on the stylus or cursor. Information can be conveyed as to which mode is active and also, when in "point" mode, as to when the coordinate information should be determined. In the embodiment illustrated in Fig. 1, the mode and point signals can be transmitted through cable 130C. Alternatively, the stylus and/or cursor can be wireless, and the mode and/or point signals can be transmitted and received optically. In the routine of Fig. 8, if the continuous mode is active, the block 820 is entered directly, whereas if the point mode is active, the inquiry of diamond 815 results in the waiting for a point command, whereupon the block 820 is entered. The blocks 820 and 830 represent the reading and storage of pixel values that are clocked out of the CCD array of optical receiving assembly 110 and the storage of the data sequentially clocked out of the array. In the present embodiment, the CCD arrays are linear arrays, and the intensity at each pixel position, after analog-to-digital conversion (as implemented by blocks 141 and 142 of Fig. 1), results in an 8 bit word representative of the intensity at each such pixel position. For an array of length 2048, for example, 2048 8 bit words (or somewhat less, if the entire array is not used) can be stored. After the array is read out, the array values are reset to zero for receiving the next optical-representative information. In similar manner, the blocks 840 and 850 represent the reading, storage, and resetting of the pixels of the CCD linear array associated with the other optical receiving assembly.

Fig. 9 is a flow diagram of an embodiment of the routine represented by the block 720 of Fig. 7, for determining the center of the light spot focused on the photosensitive surface of the CCD array, and which typically produces a pixel intensity pattern of the type which was illustrated in Fig. 5A.

In the present embodiment, a routine is used for obtaining the center position of the light spot by determining the positive-going and negative-going crossings of a reference that depends on the maximum intensity. This is illustrated in Fig. 5B, which shows the same characteristic pattern as Fig. 5A. The dashed line 510 is the maximum intensity level I_{max} and the dashed line 520 is at one-half the maximum intensity level, $I_{max}/2$. The positive-going crossing of $I_{max}/2$ is at pixel position P_1, and the negative-going crossing is at pixel position P_2. The spot center is taken to be at a pixel position P_3, which is the average of P_1 and P_2.

In Fig. 9, a determination is made (block 910) of the largest stored pixel value, and it is designated I_{max}. The block 920 is then entered, this block representing the setting of a threshold that is determined from the previously obtained maximum value. As above indicated, in the present embodiment, the threshold is set at a level of $I_{max}/2$. [Other threshold selection could alternatively be employed.] A search is then implemented (block 930), beginning at the lowest numbered pixel position (i.e., starting from the left in Fig. 5B), for the pixel position at which the threshold is first exceeded, and this pixel position is designated P_1. The search is then sequentially continued (block 940) for the next pixel position where the pixel intensity is below the $I_{max}/2$ threshold. The just previous pixel position is designated P_2. The block 950 is then entered, this block representing the averaging of the pixel positions P_1 and P_2 to obtain a position at about the center of the light spot, this position being designated P_3. The block 960 represents the repeating of the routine to obtain the spot center position P_3 for the other sensor. It will be understood that other techniques for determining a pixel reference position of the spot or its center can be employed.

Referring to Fig. 10, there is shown a routine, represented in Fig. 7 by the block 730, for determining the respective angles of arrival of the incident light from the spot center positions P_3 of the respective sensors. In the present embodiment, the spot center position is in a substantially linear relationship with the arrival angle of the received light. For example, in one operating embodiment, the sensor included about 1600 pixel positions representative of arrival angles from plus 60 degrees to minus 60 degrees with respect to the center of the CCD detector array. In this example, the arrival angle of the light can be determined from the relationship:

$$\text{Angle} = (P_c - P_0)(.075) \text{ degrees} \qquad (11)$$

, where P_c is the spot center pixel position on the positive or negative reference side of the center pixel position, P_0, of the array. For example, if P_0 is 800 and P_c for a given spot is 550, Angle would be -18.75 degrees. For a particular optical receiving assembly, P_0 can be determined empirically after fabrication. If desired, the Angle can alternatively be determined from a look-up table (e.g. in a read-only memory). Also, and desired correction could be implemented. For example, if the greater angular cut of the fibers near the edges of the input surface 252 results in a photosensitive element "seeing" light from a different number of fibers, a correction could be implemented to enhance angular accuracy.

In the routine of Fig. 10, the block 1015 represents the reading in of the previously computed and stored spot center pixel position P_c for the optical receiving assembly 110. The arrival angle, with respect to the zero angle, is then determined (block 1025), such as from the relationship (11). The process is then repeated to obtain the arrival angle for the other optical receiving assembly, as represented by the blocks 1035 and 1045. As described above, the arrival angles associated with particular center pixel positions on each photosensitive array may be determined (empirically, or otherwise), and loaded in a look-up table, such as in a ROM. The look-up table could then be interrogated to obtain the arrival angle associated with a particular center pixel position.

Referring to Fig. 11, there is shown a routine, represented in Fig. 7 by the block 740, for determining the position of the moveable element 130 from the previously determined and stored arrival angles. In the present embodiment, position is determined in terms of rectangular coordinates, and is in accordance with the equations (10) and (7), first described above in conjunction with Fig. 6. The blocks 1110 and 1120 respectively represent the determination of the tangents of the arrival angles $(\phi+\beta)$ and $(\alpha+\theta)$. This can be implemented, for example, using a look-up table of tangent values that is stored in a read-only memory (ROM), such as the ROM 156 illustrated in Fig. 1. If desired, a conventional interpolation routine can be provided to obtain tangent values of greater accuracy than a limited number of values stored in a look-up table. The x coordinate is then computed in accordance with the relationship (10), as represented by the block 1130. The y coordinate can then be computed (block 1140) in accordance with the relationship (7), whereupon the determined coordinates can be stored, displayed, and/or read out (block 1150) to a companion system (not shown).

Fig. 12 illustrates a moveable element 130B that can be used, for example, in the Fig. 1 embodiment, and is in the form of a moveable cursor that preferably slides along a flat surface and has a central cross-hair or reticle at its center designated by reference numeral 1215. In this embodiment, light is emitted azimuthally, with relative uniformity, by employing several light-emitting elements 1225 arranged in a ring. [References herein to ring-shaped and toroidal-shaped include partial rings and partial toroids.] The light-emitting elements may be, for example, light-emitting diodes that emit substantially in the infrared portion of the optical spectrum. Preferably, the cursor provides substantially uniform azimuthal emission over at least 180 degrees. The diodes can be coupled by conductors with a source of power in the cursor, such as a battery, indicated at 1235, or can be coupled via a cable to a power source (not shown in Fig. 12). A diffuser 1240 can be provided to enhance azimuthal light uniformity.

The efficiency of the cursor illustrated in Figure 12A can be substantially increased by directing light that would otherwise be lost in the vertical direction, into a generally flat beam. In the embodiment of Figure 12B, this is achieved with a toroidal lens 1280 having a convex periphery. As seen conceptually in the cross-section of Figure 12C, the lens 1280 tends to collimate the light from the ring of emitters so that more of the light energy is in an appropriate vertical range to be received by the optical receiving assemblies, thereby reducing wasted light and increasing the light energy received at the detector arrays. The toroidally shaped lens can, if desired, have a curved inner surface, as illustrated in cross section in Figure 12D. The lens can be formed, for example, of glass or plastic, and can be fitted on the cursor or mounted by any suitable means.

Referring to Fig. 13, there is shown an embodiment wherein the moveable element 130C reflects light from one or more remote sources toward the optical receiving assemblies 110 and 120. In the illustration, infrared sources 1310 and 1320 are located directly above the respective optical receiving assemblies 110 and 120, and significant portions of the light from the sources are reflected back to the respective optical receiving assemblies by a ring-shaped or barrel-shaped cursor (130C) which can have a mirror-like metal surface. The "x" on the cursor represents the reticle, which is the virtual center of the cursor. The cursor can be conventionally provided with a rear body 131 (not fully shown).

The invention has been described with reference to particular preferred embodiments, but variations within the spirit and scope of the invention will occur to those skilled in the art. For example it will be understood that the optical receiving assemblies can be placed at any desired positions, with great flexibility. Further, by using further optical receiving assembly(s), further angle measurements can be implemented and, if desired, three dimensional position determination can be implemented. It will also be understood that other coordinate systems, such as polar coordinates, could be used.

CLAIMS:

1. Apparatus for determining the position of a moveable element, comprising:

means for causing light to emanate from the moveable element;

first and second spaced apart optical receiving assemblies for receiving light from the moveable element;

each of said optical receiving assemblies including an array of photosensitive elements, and optical means for directing received light to a region on said array that is related to the angle at which said light is received;

electronic processing means responsive to the outputs of said arrays for determining said angles at which said light is received; and

means for determining the position of the moveable element from the determined angles.

2. Apparatus as defined by claim 1, wherein said optical means includes a fiber optical block having a multiplicity of optical fibers.

3. Apparatus as defined by claim 1, wherein said optical means comprises a cylindrical lens for receiving light from the moveable element, and a fiber optical block, formed of a multiplicity of optical fibers, optically coupled between said cylindrical lens and said array of photosensitive elements.

4. Apparatus as defined by claim 2 or 3, wherein said array of photosensitive elements is a flat array, and wherein said fiber optical block has a curved input face and a flat output face, with the optical fibers arranged to carry light from the input face to the output face.

5. Apparatus as defined by claim 4, wherein said curved input face is a cylindrical surface that conforms to the contour of said cylindrical lens.

6. Apparatus as defined by claim 4, wherein said array of photosensitive elements is a linear array.

7. Apparatus as defined by claim 4, wherein said array of photosensitive elements is a linear array, and wherein the flat output face of said fiber optical block is elongated to

conform to said array.

8. Apparatus as defined by any of claims 1-7, wherein said processing means includes means for determining the center position of a light spot on said array.

9. Apparatus as defined by any of claims 1-7 wherein said means for causing light to emanate from the moveable element comprises a source of light mounted on said moveable element.

10. Apparatus as defined by claim 9, wherein said light source comprises at least one infrared source.

11. Apparatus as defined by any of claims 1-7 wherein said means for causing light to emanate from the moveable element comprises at least one source of light remote from said moveable element, and a reflector on said moveable element for reflecting light from the source of light toward said optical receiving assemblies.

12. Apparatus as defined by claim 9, wherein said light source comprises a source having substantially uniform azimuthal emission over at least 180 degrees.

13. Apparatus as defined by claim 9, wherein said light source includes an array of light emitters along a generally circular arc.

14. Apparatus as defined by claim 13, further comprising a toroidal shaped lens disposed around the outside of said circular arc.

15. Apparatus as defined by any of claims 2-7, further comprising means for changing the direction of at least some of the light received at the input face of said fiber optical block.

16. The optical receiving assembly as defined by claim 15, wherein said means for changing the direction of at least some of the light received at said fiber optical block comprises a light diffuser disposed in front of input face of said fiber optical block.

17. The optical receiving assembly as defined by claim 16, wherein said light diffuser comprises a coating of light diffusing material coated on the input face of said fiber

optical block.

18. The optical receiving assembly as defined by claim 17, wherein said coating comprises a translucent ceramic material.

19. Apparatus for determining the angle of arrival of light from a remote light source, comprising:

an optical assembly including an array of photosensitive elements, and optical means for directing received light to a region on said array that is a function of the angle at which said light is received; and

electronic processing means responsive to the output of said array for determining the angle at which said light is received.

20. Apparatus as defined by claim 19, wherein said optical means includes a fiber optical block having a multiplicity of optical fibers.

21. Apparatus as defined by claim 19, wherein said optical means comprises a cylindrical lens for receiving light from the moveable element, and a fiber optical block, formed of a multiplicity of optical fibers, optically coupled between said cylindrical lens and said array of photosensitive elements.

22. Apparatus as defined by claim 21, wherein said array of photosensitive elements is a flat array, and wherein said fiber optical block has a curved input face and a flat output face, with the optical fibers arranged to carry light from the input face.

23. Apparatus as defined by any of claims 19-22 wherein said array of photosensitive elements is a linear array.

24. Apparatus as defined by claim 23, wherein said processing means includes means for determining the center position of a light spot on said array.

25. Apparatus as defined by claim 23 or 24, further comprising a light diffuser disposed in front of the input face of said fiber optical block.

26. Apparatus as defined by claim 25, wherein said light diffuser comprises a coating of light diffusing material

coated on the input face of said fiber optical block.

27. Apparatus as defined by claim 26, wherein said coating comprises a translucent ceramic material.

28. A light-emitting cursor for use in an optical digitizing apparatus, comprising:

a ring-shaped light source; and

a toroidal-shaped lens disposed around the outside of said light source, and operative to collimate light from said light source.

29. The light-emitting cursor as defined by claim 28, wherein said ring-shaped light source comprises a plurality of light sources arranged in the shape of a ring.

30. The light-emitting cursor as defined by claim 29, wherein said plurality of light sources comprises several light-emitting diodes.

31. The light-emitting cursor as defined by claim 29 or 30, wherein said plurality of light sources comprise infrared sources.

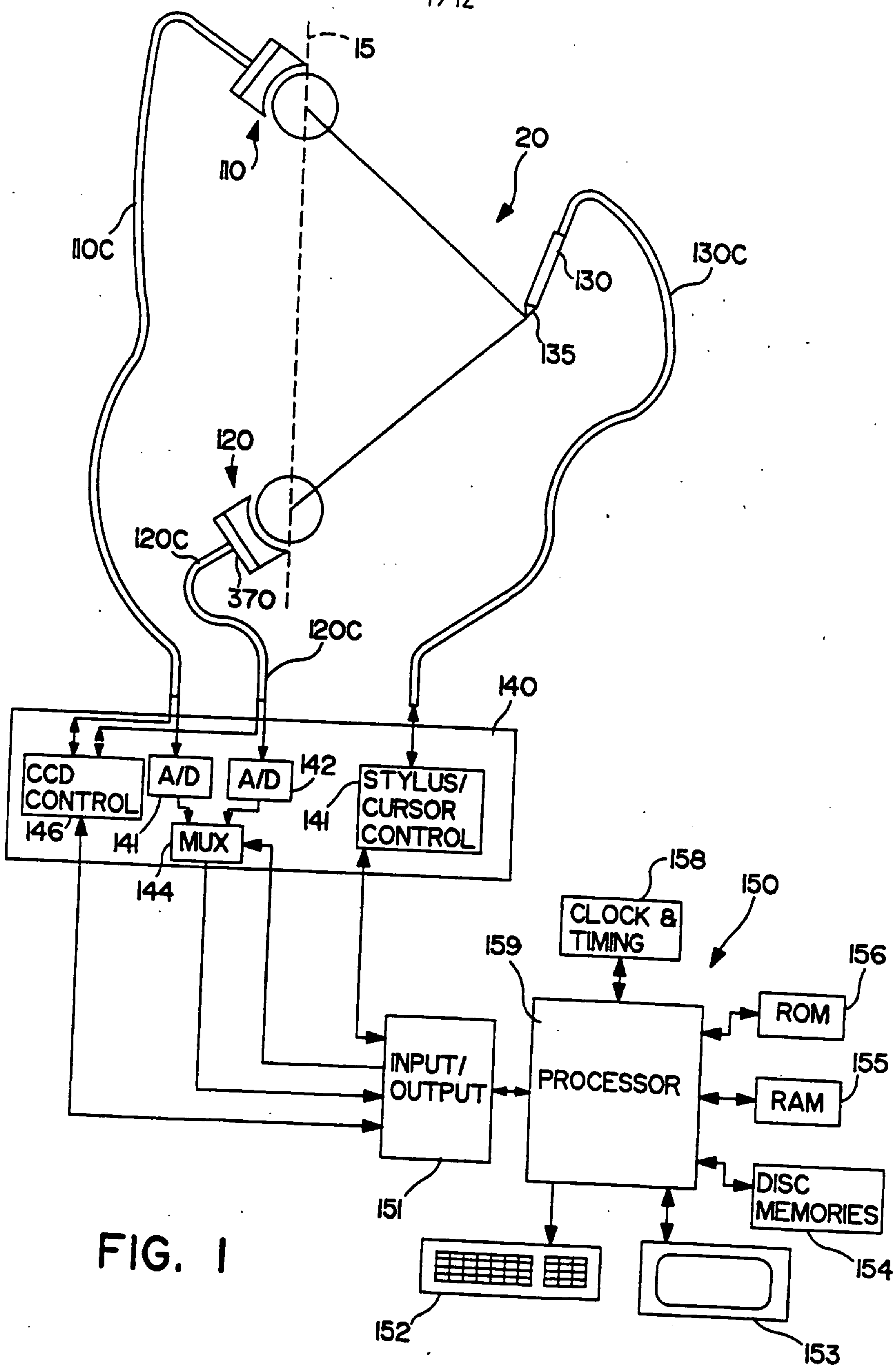

15
20
110
110C
130
130C
135
120
120C
370
120C
140
CCD CONTROL
A/D
A/D
142
STYLUS/ CURSOR CONTROL
146
141
141
MUX
144
158
CLOCK & TIMING
150
159
156
ROM
PROCESSOR
INPUT/ OUTPUT
155
RAM
DISC MEMORIES
151
154
152
153

FIG. 1

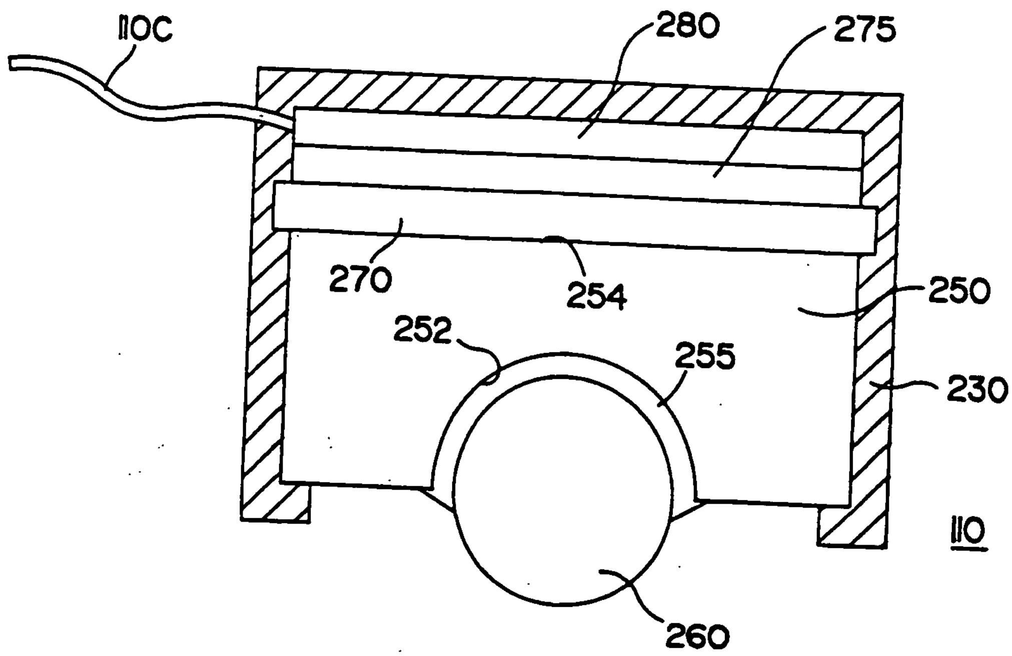


FIG. 2

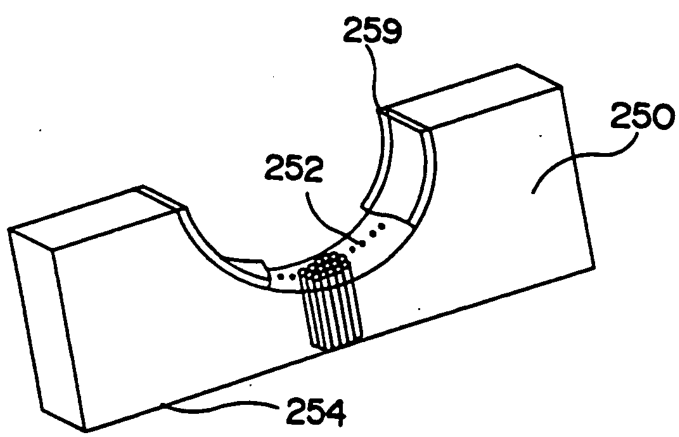


FIG. 3

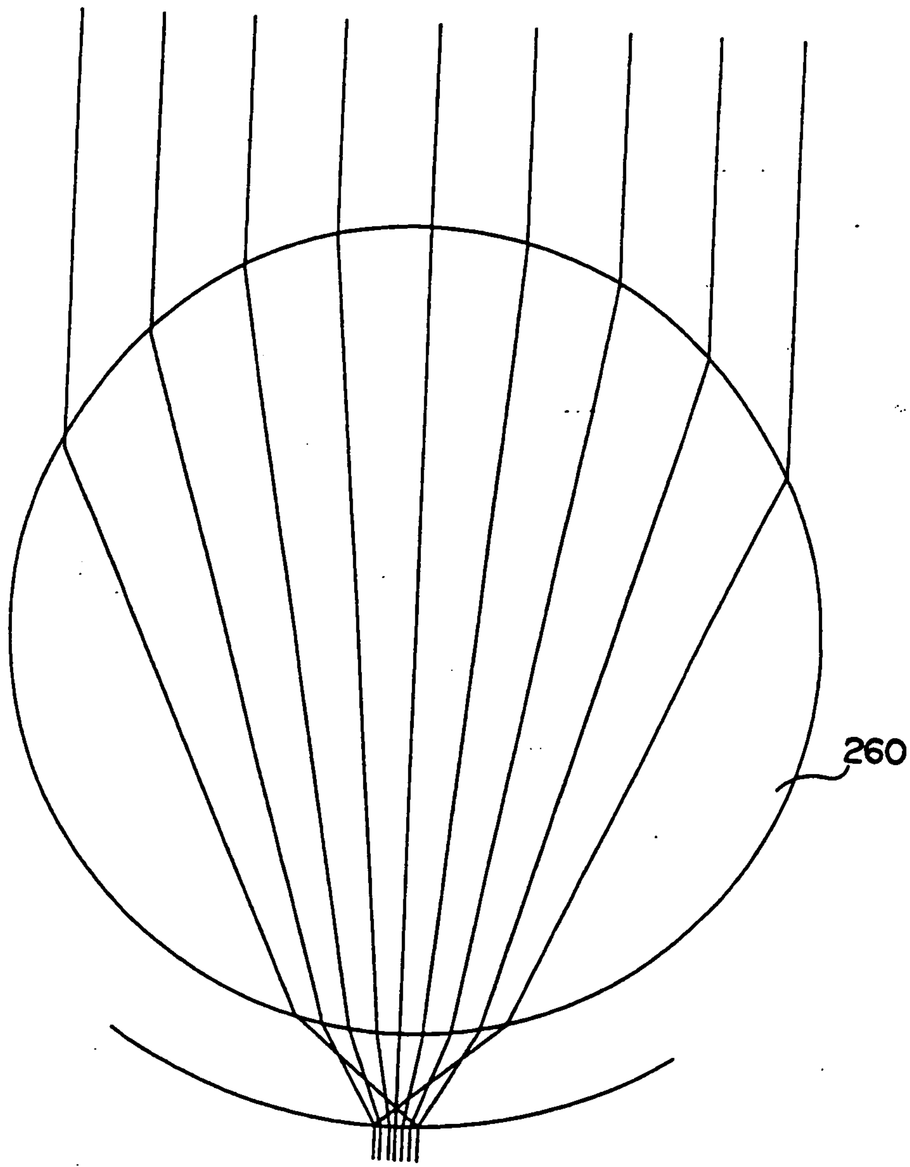


FIG. 4

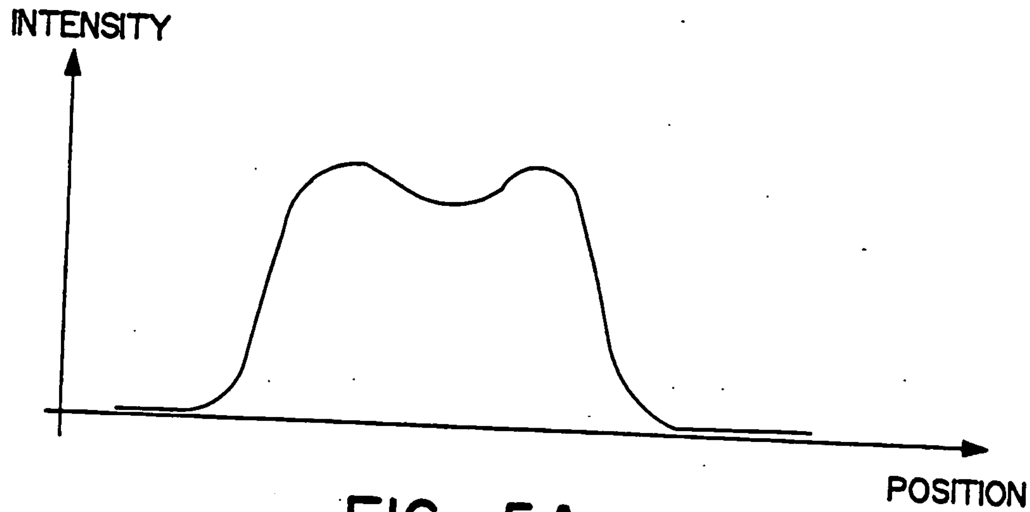

INTENSITY
POSITION

FIG. 5A

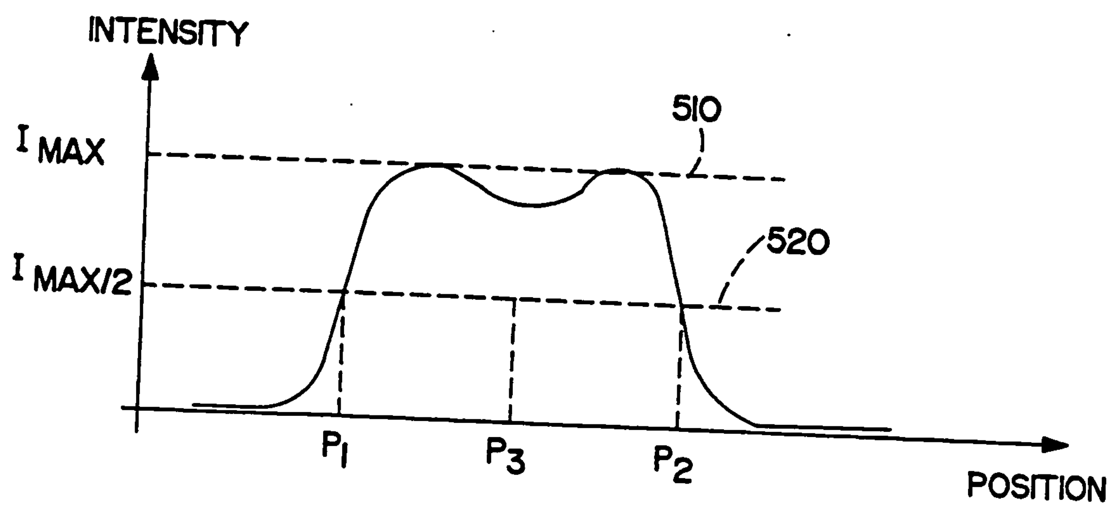

INTENSITY
I MAX
510
520
I MAX/2
P1
P3
P2
POSITION

FIG. 5B

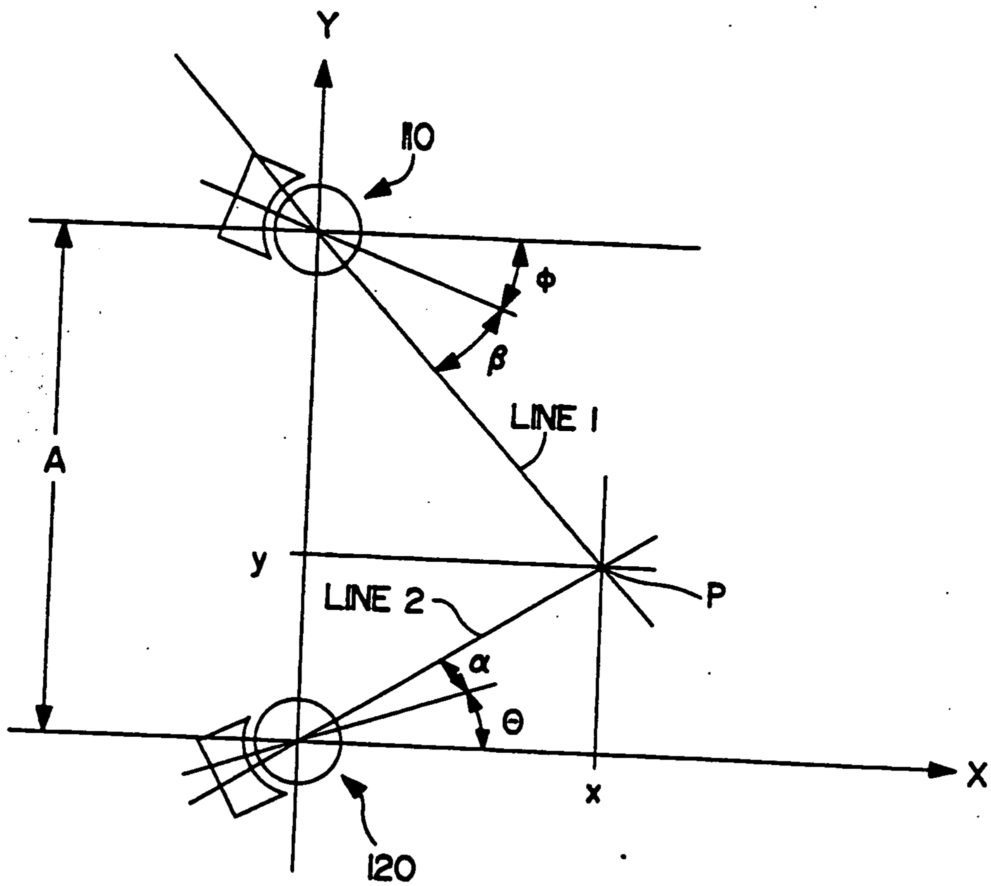


FIG. 6

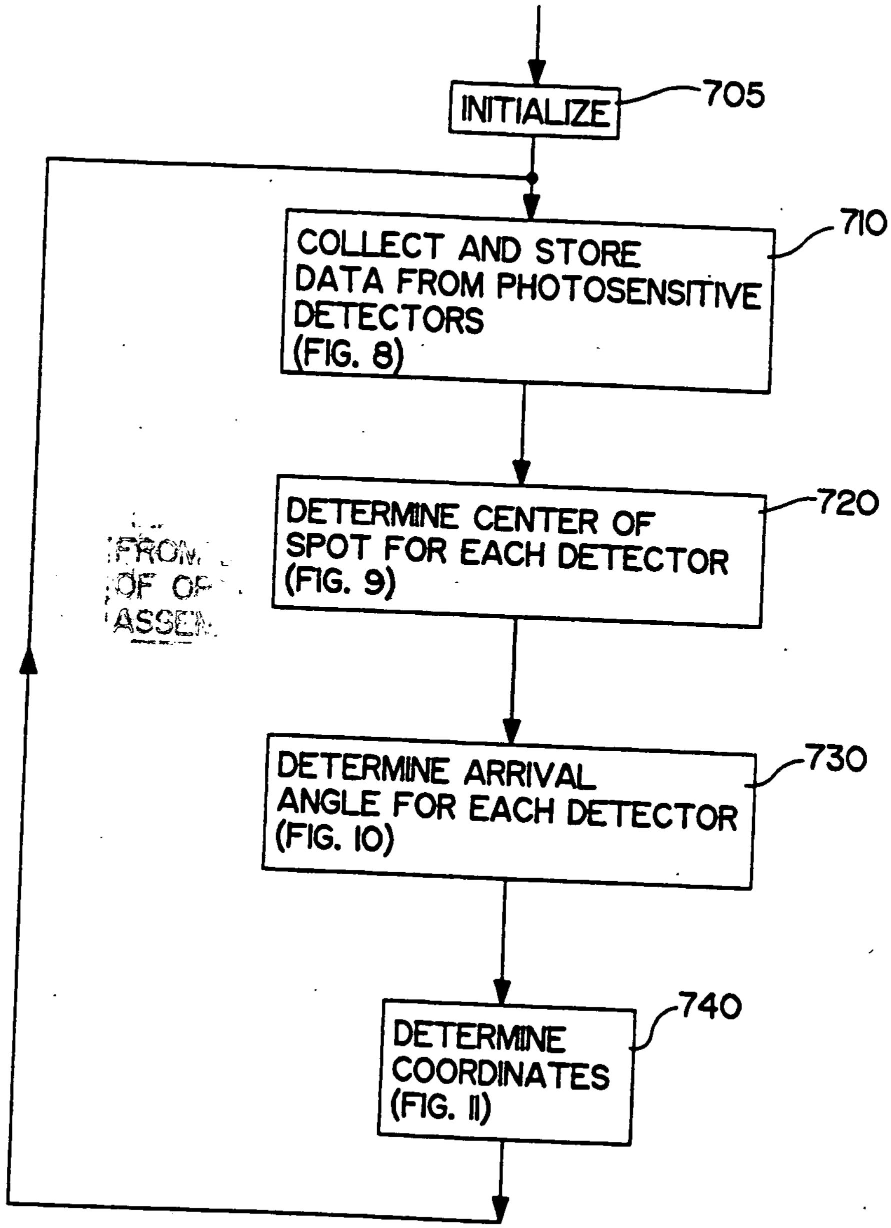

INITIALIZE
705
COLLECT AND STORE DATA FROM PHOTOSENSITIVE DETECTORS (FIG. 8)
710
DETERMINE CENTER OF SPOT FOR EACH DETECTOR (FIG. 9)
720
DETERMINE ARRIVAL ANGLE FOR EACH DETECTOR (FIG. 10)
730
DETERMINE COORDINATES (FIG. 11)
740

FIG. 7

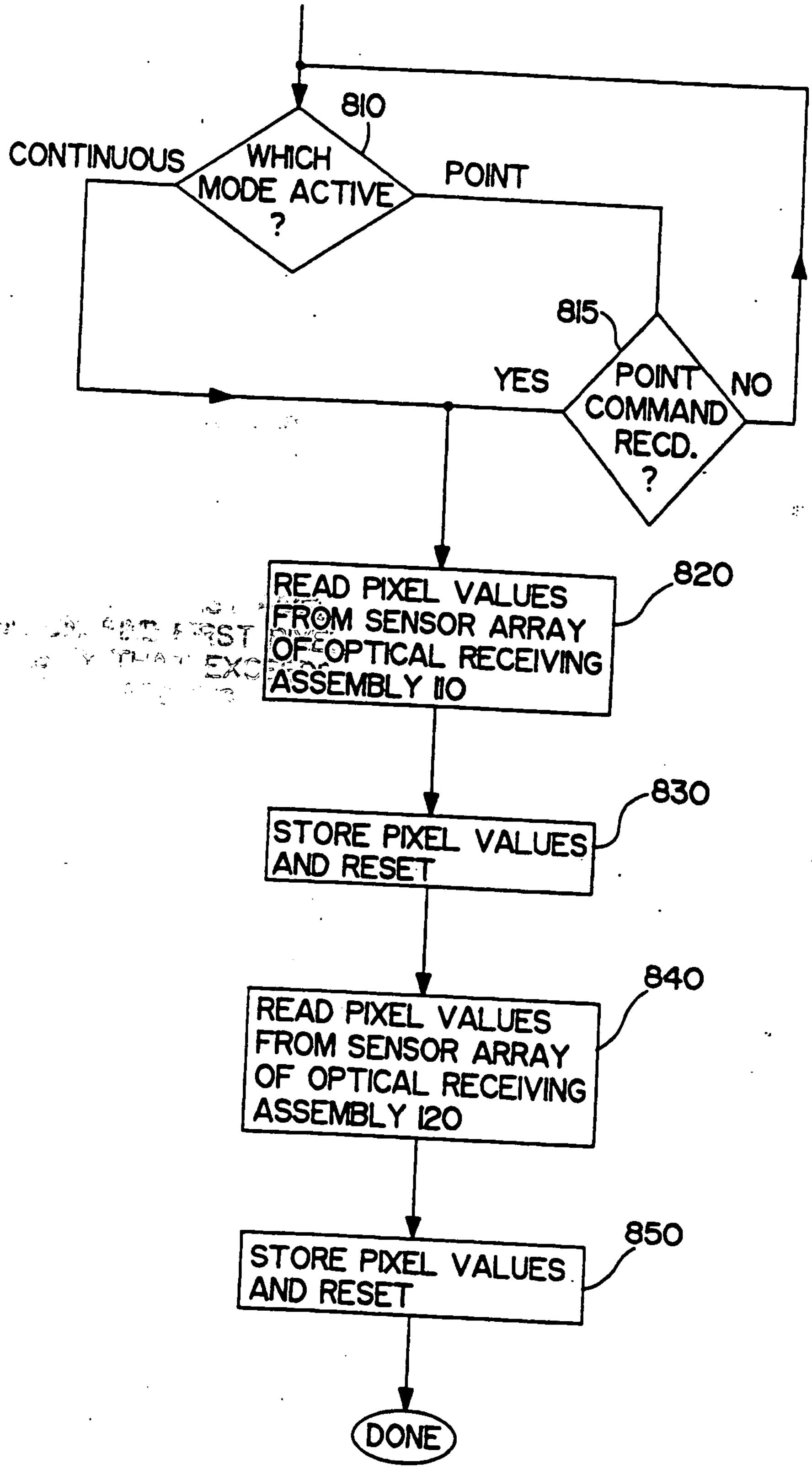

810
CONTINUOUS
WHICH MODE ACTIVE ?
POINT
815
YES
POINT COMMAND RECD. ?
NO
READ PIXEL VALUES FROM SENSOR ARRAY OF OPTICAL RECEIVING ASSEMBLY 110
820
STORE PIXEL VALUES AND RESET
830
READ PIXEL VALUES FROM SENSOR ARRAY OF OPTICAL RECEIVING ASSEMBLY 120
840
STORE PIXEL VALUES AND RESET
850
DONE

FIG. 8

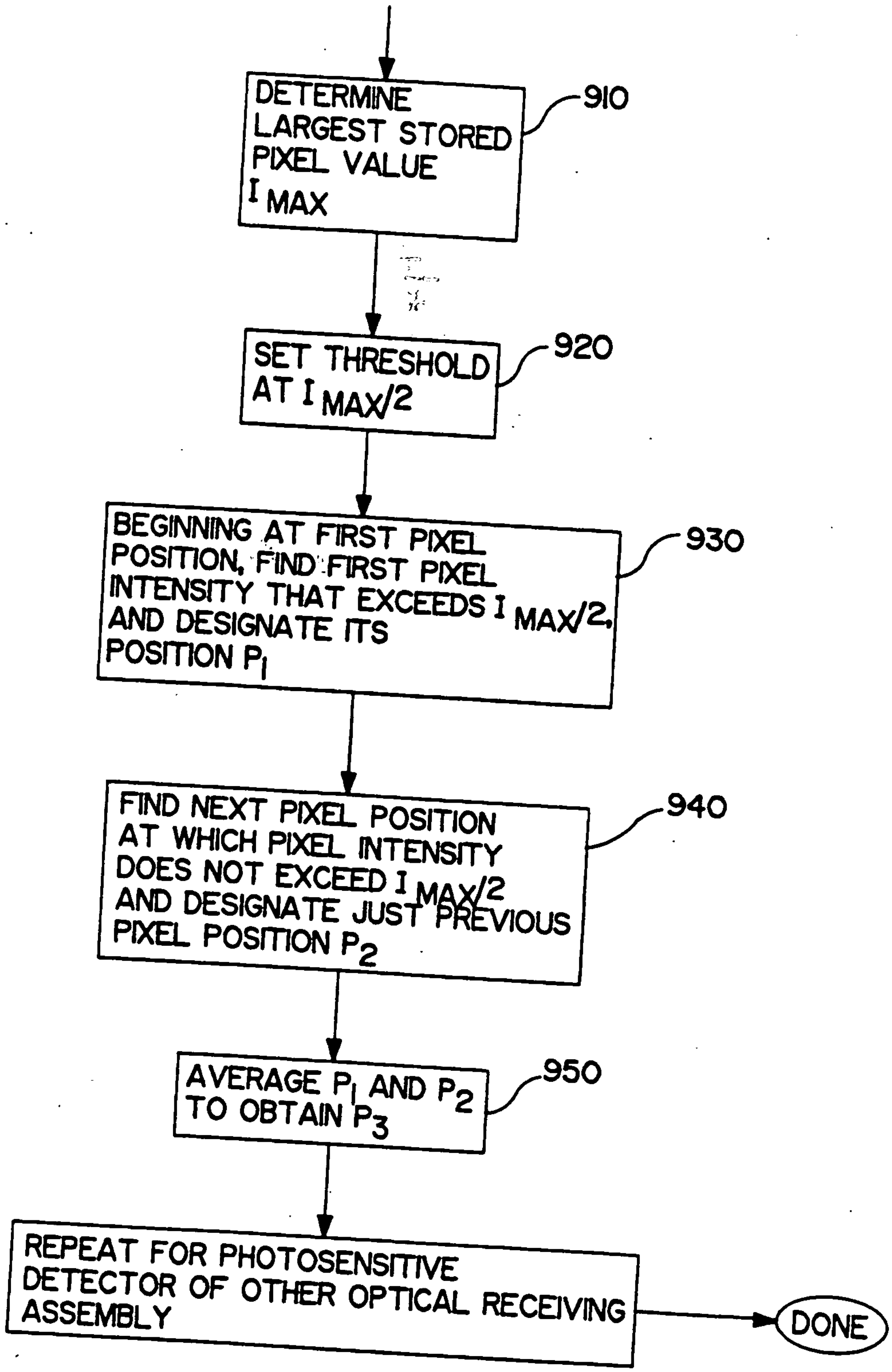

DETERMINE LARGEST STORED PIXEL VALUE I MAX
910
SET THRESHOLD AT I MAX/2
920
BEGINNING AT FIRST PIXEL POSITION, FIND FIRST PIXEL INTENSITY THAT EXCEEDS I MAX/2, AND DESIGNATE ITS POSITION P1
930
FIND NEXT PIXEL POSITION AT WHICH PIXEL INTENSITY DOES NOT EXCEED I MAX/2 AND DESIGNATE JUST PREVIOUS PIXEL POSITION P2
940
AVERAGE P1 AND P2 TO OBTAIN P3
950
REPEAT FOR PHOTOSENSITIVE DETECTOR OF OTHER OPTICAL RECEIVING ASSEMBLY
DONE

FIG. 9

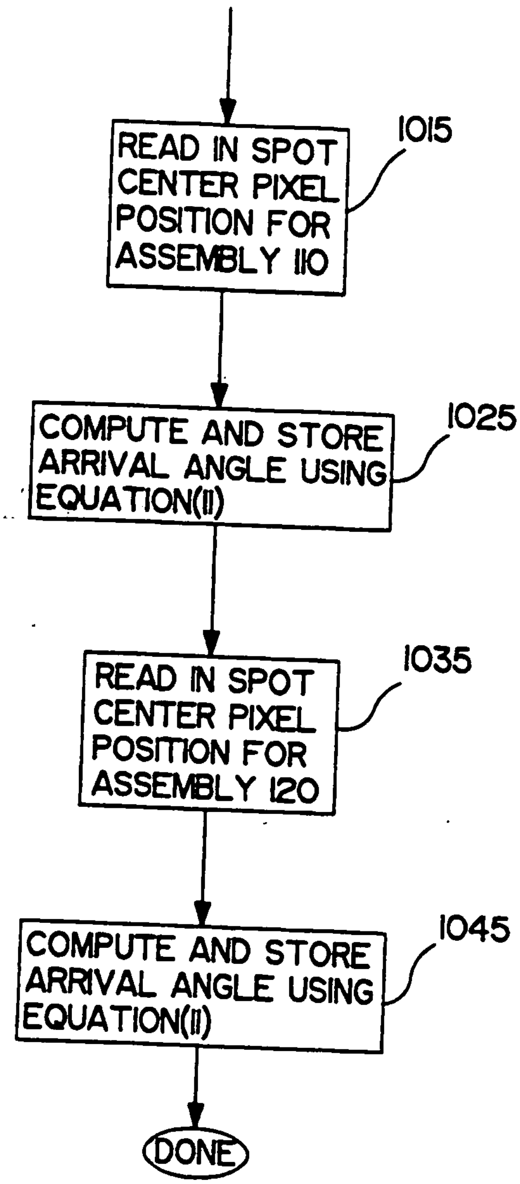

READ IN SPOT CENTER PIXEL POSITION FOR ASSEMBLY 110
1015
COMPUTE AND STORE ARRIVAL ANGLE USING EQUATION(II)
1025
READ IN SPOT CENTER PIXEL POSITION FOR ASSEMBLY 120
1035
COMPUTE AND STORE ARRIVAL ANGLE USING EQUATION(II)
1045
DONE

FIG. 10

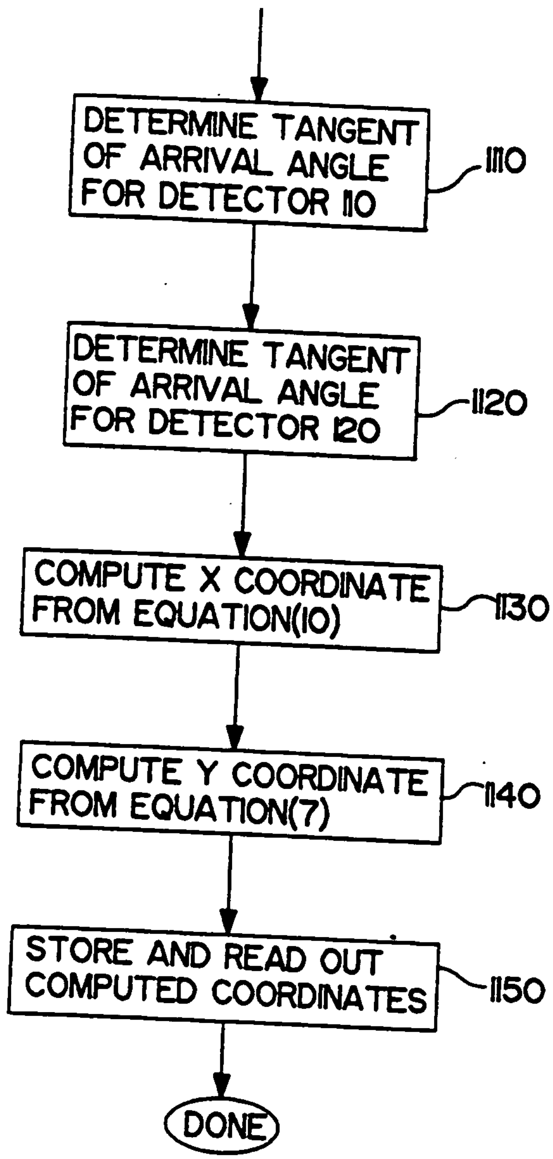

DETERMINE TANGENT OF ARRIVAL ANGLE FOR DETECTOR 110
1110
DETERMINE TANGENT OF ARRIVAL ANGLE FOR DETECTOR 120
1120
COMPUTE X COORDINATE FROM EQUATION(10)
1130
COMPUTE Y COORDINATE FROM EQUATION(7)
1140
STORE AND READ OUT COMPUTED COORDINATES
1150
DONE

FIG. 11

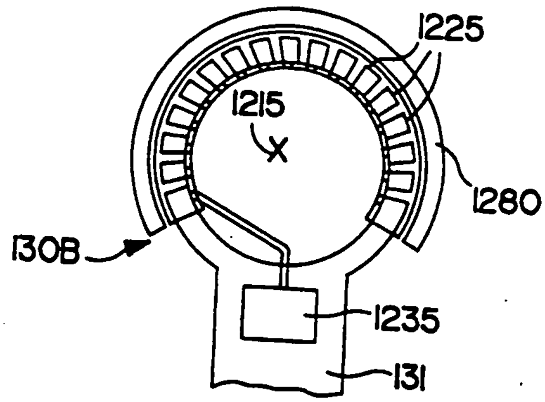


FIG. 12B

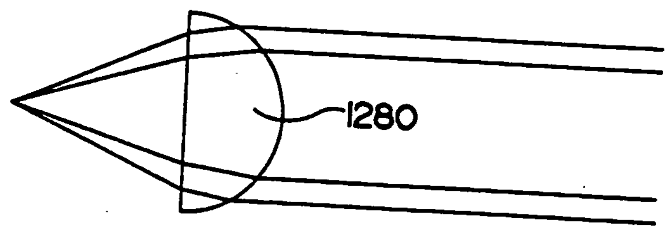


FIG. 12C

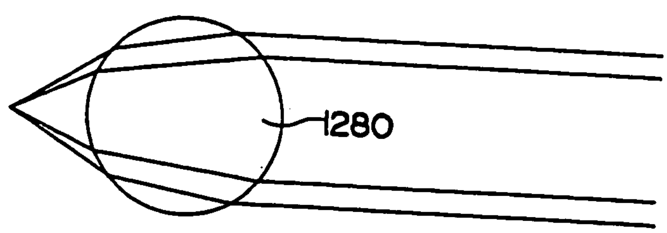


FIG. 12D

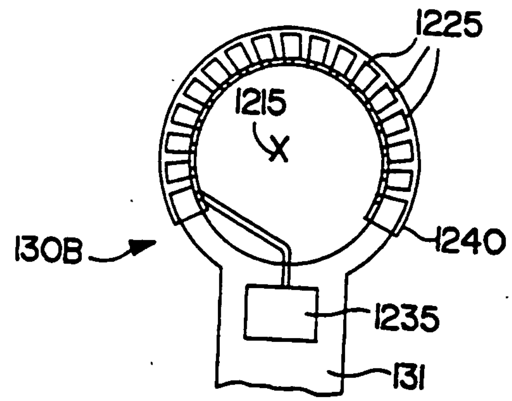


FIG. 12A

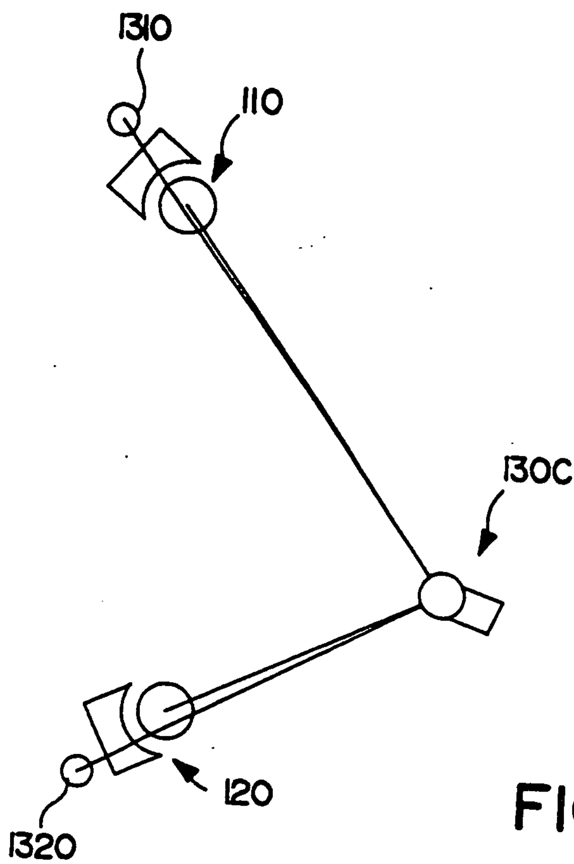


FIG. 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/07531

A. CLASSIFICATION OF SUBJECT MATTER
IPC(5) :GO1B 11/26; HO3M 1/22; G09G 3/00
US CL :Please See Extra Sheet.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
U.S. : Please See Extra Sheet.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
APS Messenger

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 4,688,933 (LAPEYRE) 25 August 1987, See entire document.	1-12, 15-27
Y,P	US, A, 5,313,542 (CASTONGUAY) 17 MAY 1994, Note Fig. 12.	2-12, 20-27
Y	US, A, 3,581,099 (FRANKE) 25 MAY 1971, Note Fig. 5.	2-12, 20-27
X -- Y	US, A, 4,782,328 (DENLINGER) 01 NOVEMBER 1988, See entire document.	1, 19 --------- 2-12, 20-27
Y	US, A, 4,896,965 (GOFF ET AL) 30 JANUARY 1990 (4:19-31)	16-18, 25-27

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be part of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 28 SEPTEMBER 1994	Date of mailing of the international search report 26 OCT 1994
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer STEPHEN C. BUCZINSKI Telephone No. (703) 308-0476

Form PCT/ISA/210 (second sheet)(July 1992)*

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/07531

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X — Y	A, 5,198,877 (SCHULZ) 30 MARCH 1993, See entire document	1, 19 ——— 2-12, 20-27
X — Y	US, A, 4,710,760 (KASDAY) 01 DECEMBER 1987, See entire document	1, 19 ——— 2-12, 20-27
X — Y	US, A, 4,936,683 (PURCELL) 26 JUNE 1990, See entire document	1, 19 ——— 2-12, 20-27
A	US, A, 5,185,638 (CONZOLA ET AL) 09 February 1993, Note Fig. 12	2-12, 20-27
A,P	US, A, 5,317,140 (DUNTHORN) 31 MAY 1994	1-12, 15-27

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/07531

A. CLASSIFICATION OF SUBJECT MATTER:
US CL :

356/1, 141.2, 341/5; 345/175; 178/18; 250/206.1, 227.13, 227.28, 227.29, 228; 385/39; 362/308, 216; 359/711, 809

B. FIELDS SEARCHED
Minimum documentation searched
Classification System: U.S.

356/1, 141.2, 341/5; 345/15; 178/18; 250/206.1, 227.13, 227.28, 227.29, 228; 385/39; 362/308, 216; 359/711, 809
356/141.4